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Assessment of commercial low viscosity resins as binders in the wood composite material *Vintorg*

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Abstract *Vintorg* is a composite product made from wood modified by high intensity microwave energy (named *Torgvin*) and then impregnated with resin. Four commercial resins were cured as resin stakes and their properties assessed. Based upon these results, *Vintorg* composites were prepared using the candidate resins and their properties tested. One trial resin exhibited superior performance and has been recommended as a phenol formaldehyde benchmark resin for *Vintorg* production trials.

Beurteilung handelsüblicher niedrigviskoser Harze als Bindemittel für den Holzverbundwerkstoff *Vintorg*

Zusammenfassung Bei *Vintorg* handelt es sich um einen Verbundwerkstoff aus Holz, der mittels hoher Mikrowellenenergie (*Torgvin*) modifiziert und anschließend mit Harz imprägniert wird. Aus vier handelsüblichen Harzen wurden quaderförmige Proben hergestellt und deren Eigenschaften geprüft. Darauf aufbauend wurden *Vintorg* Verbundwerkstoffe mit diesen Harzen hergestellt und deren Eigenschaften geprüft. Eines der Versuchsharze führte zu besonders guten Ergebnissen und wurde somit als Richtwert für Phenolformaldehydharz für weitere Untersuchungen von *Vintorg* empfohlen.

1 Introduction

The application of intensive microwave energy in the processing of timber generates an internal steam pressure that ruptures the weaker elements of the timber structure, improving radial permeability and causing a rapid reduction in moisture content. The level of modification is a function of the time and power that the timber is processed with. Highly modified timber has been coined *Torgvin* (Fig. 1) after the original workers (Torgovnikov and Vinden 2006, Vinden et al. 2004, Torgovnikov and Vinden 2002). A composite product prepared from *Torgvin* has been termed *Vintorg* (Fig. 2). A suitable resin for *Vintorg* production needs to be able to penetrate wood easily and have a short curing time.

Novel resins formulated and produced at the University of Melbourne for the CRC Wood Innovations are based on phenol formaldehyde adhesives and prepolymers. Currently *Vintorg* is produced with two reference resins – Rubinate 1780 (an isocyanate) and Sylvic M550 (a melamine urea formaldehyde resin). Given the performance properties of these two resins it was deemed necessary to ex-

Fig. 1 *Eucalyptus regnans* F. Muell. microwave modified material (*Torgvin*) ($90 \times 60\ mm^2$)
Abb. 1 *Eucalyptus regnans* F. Muell. nach Mikrowellenbehandlung (*Torgvin*) ($90 \times 60\ mm^2$)

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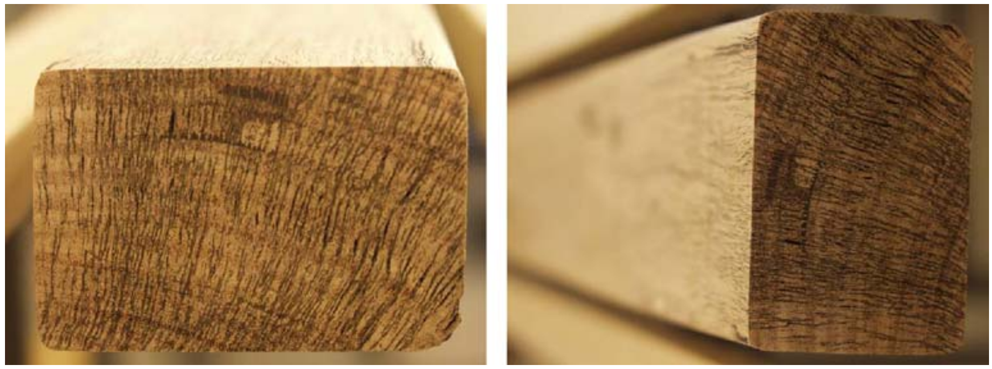

Fig. 2 *Eucalyptus obliqua* L'Herit. composite material (*Vintorg*) (60×45 mm^2)
Abb. 2 *Eucalyptus obliqua* L'Herit. Verbundwerkstoff (*Vintorg*) (60×45 mm^2)

amine commercially available phenol formaldehyde resins to accurately define the performance attributes of the in house resins. Following discussions with Borden Chemical Australia Pty Ltd the CRC Wood Innovations was provided with four resins to trial in the *Vintorg* production process.

The objective of this study was to assess low molecular weight commercial resins for suitability in the manufacture of the wood composite *Vintorg*. Gel times and viscosities of the resin solutions were to be determined. The properties of the cured polymers were to be assessed by manufacturing resin stakes in moulds and determining the stiffness and hardness of the stakes. These properties were anticipated to be an estimate of the potential properties of the timber product. The processing and performance attributes of a *Vintorg* composite manufactured from messmate (Eucalyptus obliqua L'Herit) was determined. Strength properties including modulus of elasticity (MOE), modulus of rupture (MOR) and hardness were used to rank performance of the messmate polymer composites. The overall aim of the work was to select a suitable resin for use as a benchmark for *Vintorg* manufacture.

2 Materials and method

Resins were obtained from Borden Chemical Australia Pty Ltd, Laverton, Victoria, Australia as Cascophen BD4503, Cascophen BD4507, Cascomel BD4508 and Cascophen BD4509 and stored in a refrigerator with the exception of Cascomel BD4508 which was stored at room temperature.

The viscosity of the four resins was found to be markedly different. The lower viscosity resins (BD4503 and BD4509) should be easier to incorporate into the timber and are expected to provide better penetration and distribution throughout the composite. Low viscosity resins can suffer from migration away from the joint leading to poor adhesion and poor product performance. Higher viscosities tend to penetrate the timber slower; if large molecules are present in the adhesive they have a tendency to be filtered out on the timber surface and do not bond all ruptures created by the production of *Torgvin*. This makes higher viscosity resins less suitable for the production of *Torgvin* and can result in the need to remove excess resin from the timber surface prior to curing in a press.

Gel times are a critical factor for determining the productivity of a manufacturing plant, faster gel times result in shorter press times and higher throughputs for composite manufacturers. The gel times determined for the resins were significantly different from one another indicating that press curing times should be similar for two of the pairs of treatments and approximately twice as long for one pair over the other pair.

The stiffness of a resin stake is an indication of the extent of cross linking within the resin. Higher cross linking within a stake results in greater rigidity and brittleness, whilst lower levels of cross linking afford a flexible stake. This property may provide an indication of performance improvement possible with the composite.

Hardness is a measure of surface resistance to deformation; the harder a surface the greater the resistance to wear and marking. This is an important property for timber flooring and was assessed in the stakes as it may provide an indication of possible performance improvements.

2.1 Resin properties

2.1.1 Resin viscosity and gel time

The viscosities of the Cascophen BD4503, Cascophen BD4507, Cascomel BD4508 and Cascophen BD4509 resins were determined using a Brookfield DV-E Digital Viscometer at 20 °C. Gel times were established at 100 °C in an oil bath with test tubes containing 10 cm^3 of the supplied resins. Ten replicates per resin were employed for both the viscosity and gel time determinations, averaged and summarized in Table 1.

Table 1 Resin properties
Tabelle 1 Harzeigenschaften

Resin number	Resin type	Gel time [100 °C]	Viscosity [Cp]
BD 4503	phenol formaldehyde	50 min	38
BD 4507	phenol formaldehyde	54 min	777
BD 4508	melamine formaldehyde	100 min	1253
BD 4509	phenol formaldehyde	100 min	43

2.1.2 Preparation of resin stakes

Water was removed from each of the Cascophen BD4503, Cascophen BD4507 and Cascomel BD4508 resins by rotary evaporation under reduced pressure at 50 °C. Resin stakes were prepared by pouring 145 cm^3 of resin into an aluminium mould, sealing the mould and curing the resin for 12 hours at 105 °C after which time the mould was allowed to cool to room temperature and disassembled. Nine replicate resin stakes ($300 \times 22 \times 22$ mm) were prepared for each supplied resin. Resin stake production for Cascophen BD4509 was not possible and results for this resin are not recorded.

2.1.3 Modulus of elasticity and hardness of resin stakes

The MOE was determined by centre point loading on a Hounsfield 10 kN strength testing apparatus. Each stake was suspended over a span of 280 mm and deflected 1 mm to ascertain the stiffness of the resin stake at a crosshead movement speed of 5 mm/min.

Hardness was determined using a modified form of the Janka indentation hardness method (Mack 1979). This determination consisted of the measurement of the force required to shatter $25 \times 25 \times 25$ mm test specimens machined from the resin stakes utilizing the hemispherical end of a steel shaft (11.28 mm $\pm$ 0.005 mm diameter) at a rate of 6.5 mm/min. Modification to the Janka indentation hardness technique was required as shattering of the sample occurred prior to indenting the sample to a depth of 5.64 mm as required by the standard (Mack 1979).

2.2 Composite Properties

Messmate (*Eucalyptus obliqua* L'Herit.) was obtained from Blackforest Timbers, Calder Hwy, Woodend, Victoria, Australia. The timber was microwaved green to produce a messmate *Torgvin* prior to being conditioned to 12% equilibrium moisture content by storage in a conditioning room at 20 °C and 65% relative humidity. Microwave of frequency 0.922 gHz was used to modify the timber with an energy input of $170\,\mathrm{kW-hr/m^3}$.

Eighteen short lengths of messmate *Torgvin* ($900 \times 60 \times 25$ mm) were docked to 430 mm in length. These timber samples equated to nine replicates for each of the four trial resins. A structured sampling regime was adopted where lengths of timber were randomly allocated a pair of resin treatments. This ensured that an even match of timber resin combinations was achieved.

Timber was heated to 70 °C and treated using a pressure soak schedule (100 kPa (gauge), 5 minutes). The nine replicate samples were then placed in a 3 m $\times$ 1.3 m Baioni platen press and cured at 150 °C for 4 hours. Production of *Torgvin* results in an expanded wood product and the use of pressure to compress the wood to its original shape and size is essential for good *Vintorg* production. Frames were used to act as limits and prevent compression of the *Vintorg* composite. This prevents densification and ensures that strength values of the timber are not influenced by compression.

Following curing, the *Vintorg* material was planed and then halved to produce specimens of dimension $400 \times 22 \times 22$ mm. The MOE, MOR and hardness of these samples was determined on a Hounsfield 10 kN strength testing machine. The MOE and MOR were determined over a span of 280 mm with a crosshead movement of 5 mm/min, whilst sample hardness was ascertained using the Janka indentation hardness method (Mack 1979).

3 Results and discussion

3.1 Resin properties

Raw data and statistical evaluations are not included in this report. A summary of results for the resin properties is presented in Table 1.

Gel times for the resins BD4503 and BD4507 were not found to be significantly different from each other. The same was found for resins BD4508 and BD4509. Resins BD4503 and BD4507 were found to cure significantly faster than BD4508 and BD4509. The influence of catalysts on properties was beyond the scope of this initial examination.

The stiffness (MOE) of stakes produced from the resins is displayed in Fig. 3. Stakes produced using the resins were all significantly different from each other with the BD4503 producing the strongest stake, followed by the BD4508. BD4507 produced the weakest stake. The stakes prepared showed little variation, providing a consistent response to the test methodology.

Resin hardness results are displayed in Fig. 4. The melamine formaldehyde resin (BD4508) was found to be significantly harder than the two phenol formaldehyde resins tested. The hardness of the phenol formaldehyde resins was almost identical.

3.2 Composite properties

A summary of resin uptake in *Vintorg* production is provided in Table 2. Samples produced with the melamine

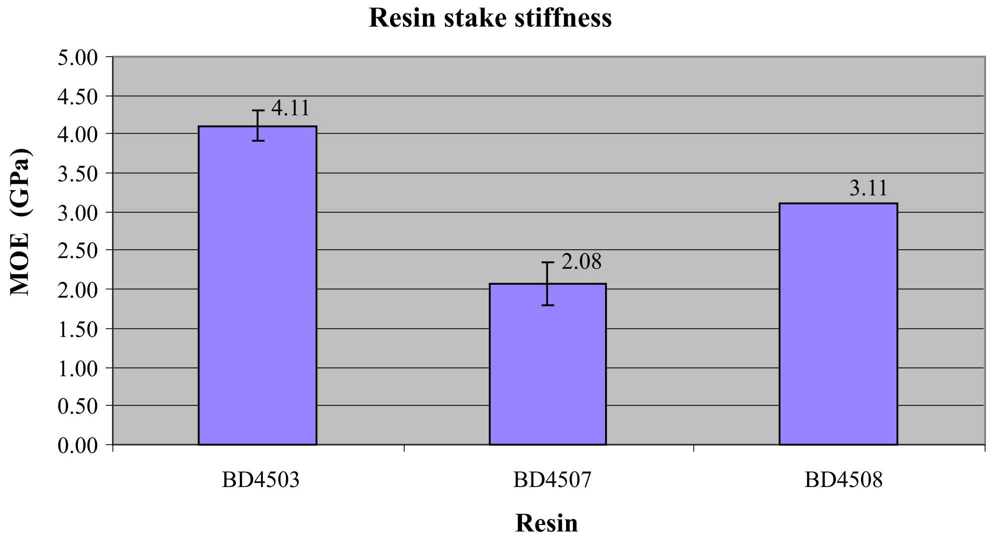

Fig. 3 Stake stiffness (MOE) as dependent on resin
Abb. 3 E-Modul (MOE) der verschiedenen Harzproben

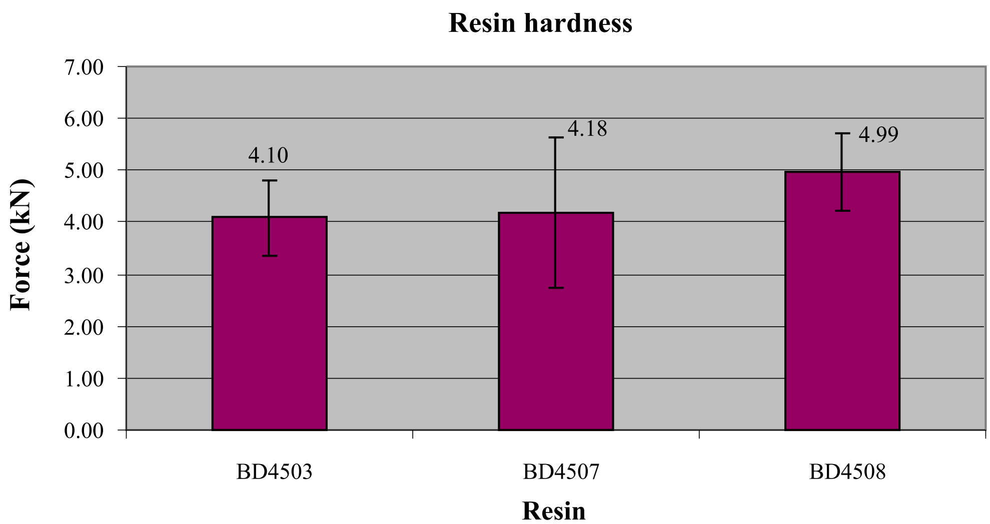

Fig. 4 Stake hardness as dependent on resin
Abb. 4 Härte der verschiedenen Harzproben

formaldehyde resin (BD4508) had the lowest uptakes, a value significantly different to the other treatments. Messmate treated with BD4509 had higher uptakes than the other treatments. Mechanical properties of the composites are shown in Figs. 5 and 6.

The *Vintorg* composite produced with BD4503 was significantly stiffer and more capable of supporting higher loadings than composites produced using BD4507 and BD4508. *Vintorg* material produced with BD4509 was not significantly different to any other composites tested.

Vintorg composite produced using BD4508 had significantly lower surface hardness than stakes produced with the phenol formaldehyde resins. The performance attributes of the phenol formaldehyde resins were not significantly different from each other.

The density of the *Torgvin* messmate used in the trials (Table 2) was not significantly different. *Torgvin* treated with the different resins produced *Vintorg* densities that were significantly different. *Vintorg* densities were related to the resin uptake. Treatments with higher resin uptakes naturally displayed the greatest density improvement (Table 2). The trend again followed in the assessment of hardness. These results strongly support the notion that these mechanical properties are influenced by resin concentration.

Statistical analysis of the *Vintorg* composites strength properties indicated that the difference in strength (MOE) observed in the messmate treated with BD4503 resin is significantly stronger than material produced with the BD4507 and BD4508 resins but not the BD4509. The stiffness of samples produced with BD4509 is not significantly different in performance to the other resin treated specimens. The statistics also indicated that a large proportion of the variation observed is due to the timber. Whilst the sampling methodology utilized in this investigation was sufficient to highlight differences in performance attributes for the four composites, future work would benefit for a fully randomized block

Table 2 Summary of *Vintorg* production
Tabelle 2 Zusammenfassung der *Vintorg*-Versuchsreihen

Sample	*Vintorg* uptakes (kg/m^3)				*Torgvin* density (kg/m^3)				*Vintorg* density (kg/m^3)			
	BD4503	BD4507	BD4508	BD4509	BD4503	BD4507	BD4508	BD4509	BD4503	BD4507	BD4508	BD4509
7A-1	90			126	751			654	916			910
8A-1		200		164		721		711	0	973		1037
10A-1			56	153			670	617			853	866
11A-1	28	33			664	686			783	787		
12A-1	221		127		634		735		864		920	
14A-1		41	155			628	677			727	908	
15A-1	115			146	779			656	904			872
16A-1		181		187		690		671		982		968
17A-3			18	156			716	682			831	897
19A-3	99	227			619	641			914	994		
22A-1	152		55		545		586		791		683	
23A-3		73	81			621	614			819	853	
24A-1	51			147	682			580	813			908
25A-3		108		133		696		603		843		943
26A-1			184	152			683	709			912	922
27A-3	104	88			776	610			940	811		
29A-3	84		6		792		666		942		761	
30A-3		169	27			580	620			856	786	
Average	105	124	79	152	694	653	663	654	874	866	834	925

design. If an estimation of timber property improvement is required then commercially processed controls cut from the same timber length would also be required.

Vintorg composites produced using BD4503 had the highest radial surface hardness. Compression testing in this direction is of particular interest in *Vintorg* based composites as it provides an indication of wood resin internal bond strength. The production of *Torgvin* causes the modification of timber ray cells resulting in the formation of cavities running in the radial direction. The resin is needed to bond these cavities together to restore and enhance the original mechanical properties of the timber. A shear test examining cleavage in the radial direction is being incorporated into the testing program. This shear test will quantify the radial and tangential strength of the timber and will be specific for *Vintorg* based composites. Incorporation of this test will result in further improvements in the mechanical properties of the *Vintorg*.

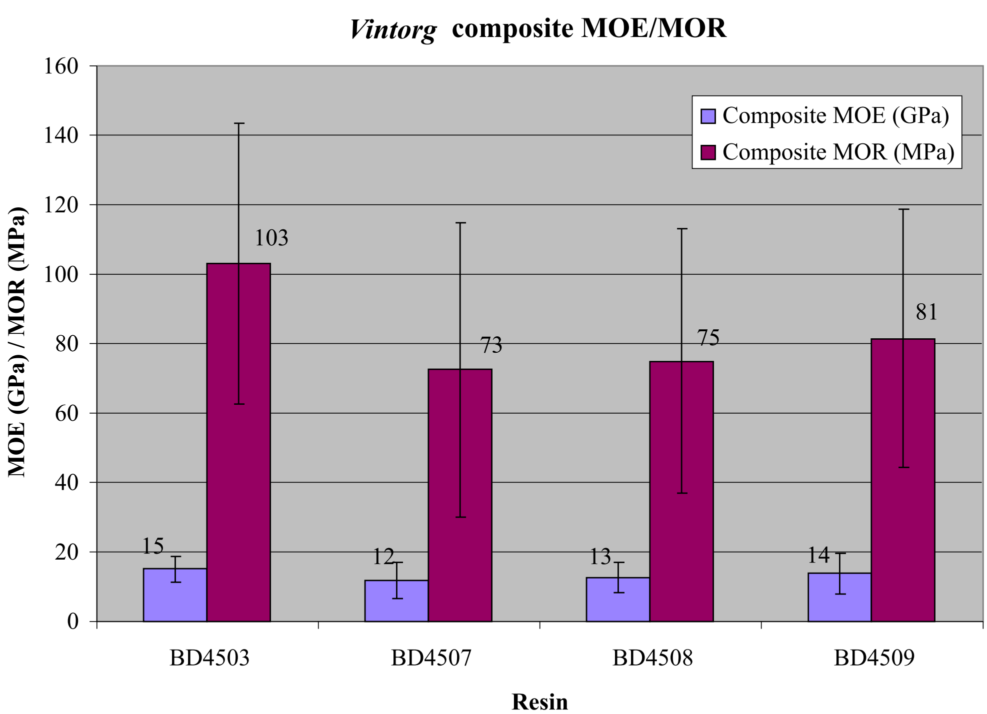

Fig. 5 *Vintorg* composite MOE/MOR as dependent on resin
Abb. 5 E-Modul/Biegefestigkeit (MOE/MOR) des Verbundwerkstoffes *Vintorg* in Abhängigkeit vom Harz

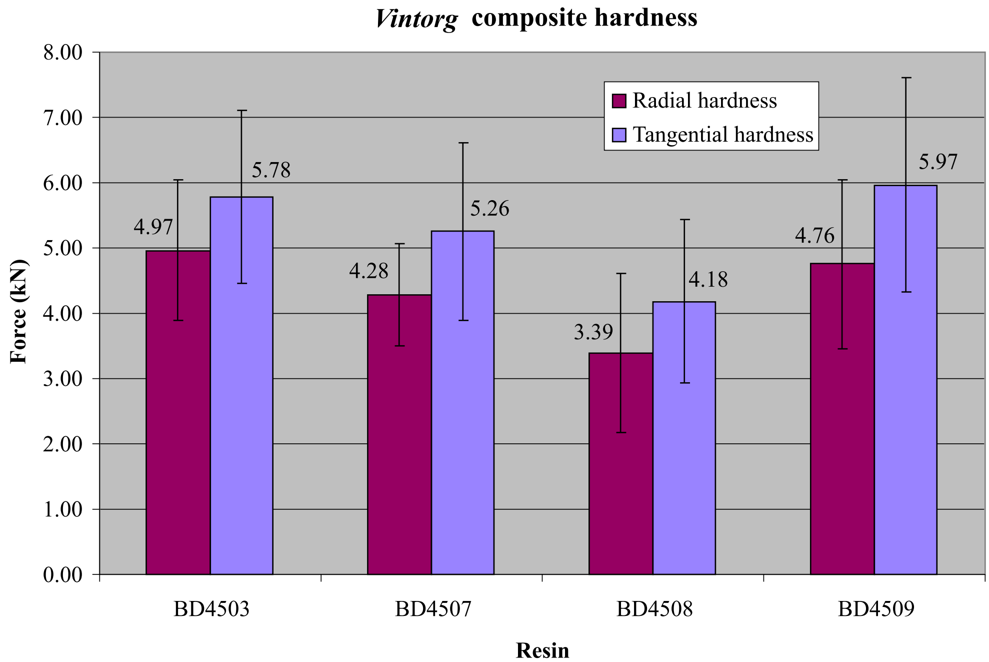

Fig. 6 *Vintorg* composite hardness as dependent on resin
Abb. 6 Härte des Verbundwerkstoffes *Vintorg* in Abhängigkeit vom Harz

4 Conclusions

4.1 Resin properties

Due to the significantly higher stiffness and low viscosity of BD4503, this resin shows promise for the manufacture of *Vintorg* based composites. The hardness of the BD4508 is appealing for *Vintorg* manufacture for timber flooring. The neutral colours of the resin stakes means that composites produced with the resins assessed will have the appearance of natural timber. Based upon this preliminary investigation, further investigation of the resins is warranted. The use of resin stakes gave consistent results and shows potential as a screening technique for candidate resins for *Vintorg* production.

4.2 Composite properties

Owing to the significantly higher strength properties seen in *Vintorg* composites produced with BD4503, the use of this resin as a benchmark for resin development is recommended. The BD4509 showed promise and could be incorporated into the testing program. Borden resin BD4509 may prove to be a better performing species if different curing regimes or timber species are utilized.

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